Application of the South Florida Regional Simulation Model in the Southern Everglades

L. Brion, S. U. S. Senarath, A. M. W. Lal, and M. Belnap

Abstract

The South Florida Regional Simulation Model (SFRSM) is used in this study to simulate flow-dynamics in the Everglades National Park (ENP). The SFRSM, a model under development by the South Florida Water Management District (SFWMD), was designed to simulate major components of the hydrologic cycle as well as the complex water management rules and policies in South Florida. This paper focuses only on the physical processes such as overland and ground water flow, evapotranspiration, levee seepage, and canal flow that dominate the hydrology within the study area. The current working version of the SFRSM, referred to as the Hydrologic Simulation Engine (HSE) is a weighted, implicit, finite-volume, rainfall-runoff model, capable of simulating two-dimensional flow using a variable mesh with arbitrarily shaped triangular elements. One-dimensional canal flow and two-dimensional overland flow are simulated in the model using the diffusive wave approximation of the Saint Venant equation. The Darcy equation is used for the one-dimensional canal seepage and two-dimensional groundwater flow calculations. Overland and groundwater flow components are fully coupled for a more realistic representation of runoff generation. This feature makes the HSE ideally suited for simulating high water tables and relatively flat terrains associated with the Everglades. Calibration results show that the HSE provides stage history-matching capabilities comparable to the South Florida Water Management Model - the more thoroughly-tested regional simulation model for the same region.

Objectives of the Study

Florida's Everglades is a unique ecosystem. Although about half of it has been lost due to anthropogenic activity, it is still the largest sub-tropical wetland wilderness in the U.S.A. The model domain used in this study encompasses a significant portion of the remaining Everglades. Although designated and protected as a National Park, the selected modeling area is adversely affected due to exotic species, nutrient enrichment, contaminants, and altered freshwater inflows. The model domain also encompasses the only remaining habitat in the world of the endangered Cape Sable Seaside Sparrow population. The Everglades as a whole is also home to 67 other endangered or threatened animal and plant species. The survival of these species is dependent on the quality, quantity, timing and distribution of the freshwater flow in the Everglades. The objective of this study is to determine if HSE can realistically simulate the hydrography in the environmentally sensitive southern Everglades region. The paper also evaluates the applicability of using automated stochastic optimization tools for calibrating the HSE. Performance of HSE is compared against another integrated surface water-groundwater simulation model, the South Florida Water Management Model, which has been the tool of choice for several years now for evaluating regional hydrologic impacts due to structural and operational alternatives related to the water resources in south Florida.

Regional hydrologic models are vital tools that can be used to effectively manage and allocate Florida's complicated (and limited) water resources. In this paper, the main focus is centered on developing simulation capabilities that accurately describe flow dynamics in the southern portion of the Everglades.

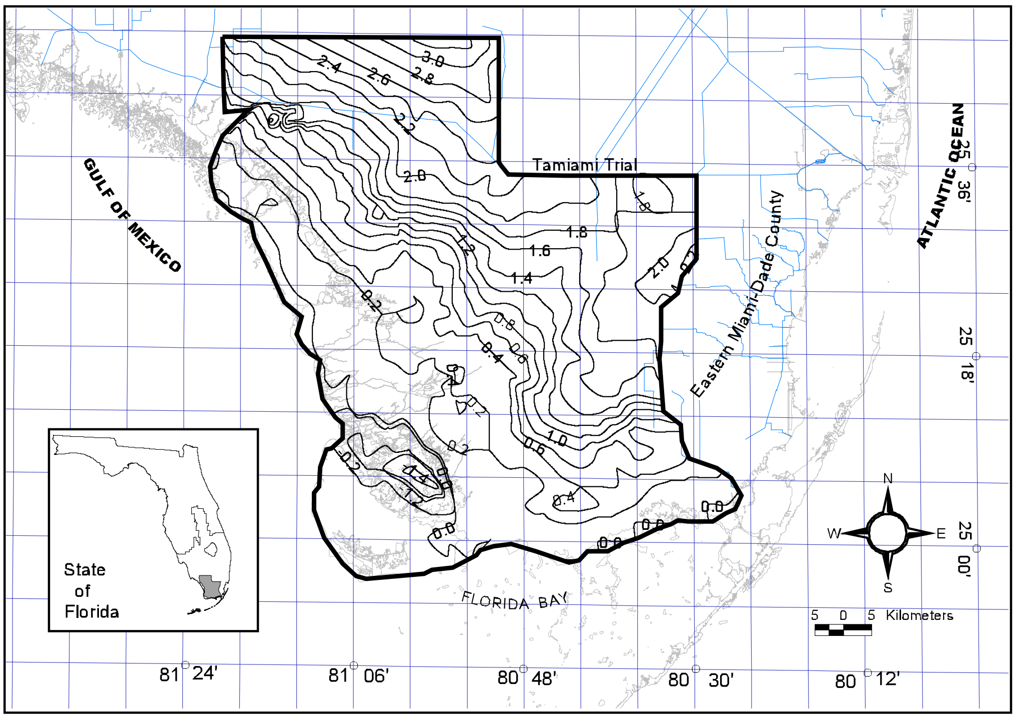

Figure 1 Model Domain for the HSE Application in the Southern Everglades

Model Setup

The model domain is illustrated in Figure 1 together with a map of the state of Florida. The elevation contours of the watershed are also illustrated in Figure 1. It encompasses a significant portion of the Everglades National Park, and the southern portion of the Big Cypress National Preserve. The western and southern borders of the model extend to the Florida Bay and the Gulf of Mexico coastlines, respectively. The model domain ends at Tamiami Trail in the north. To the east of the model boundary is the highly urbanized eastern Miami-Dade county. The triangular mesh of HSE is conformed to account for all major highways and levees within the model domain. Part of the model domain coincides with the South Florida Water Management Model (SFWMM) domain. The SFWMM is a regional-scale computer model that simulates the hydrology and the management of the water resources system in South Florida extending from Lake Okeechobee which is about 100 km north of ENP to Florida Bay (SFWMD, 1999). It covers an area of 19,680 square kilometers (7,600 square miles) using a mesh of 3.2-km x 3.2-km (2-mi x 2-mi) cells. This model simulates the major components of the hydrologic cycle in south Florida including rainfall, evapotranspiration, infiltration, overland and groundwater flow, canal flow, canal-groundwater seepage, levee seepage and groundwater pumping. The SFWMM has been calibrated and verified using water level and discharge measurements at hundreds of locations distributed throughout the region within the model boundaries (SFWMD, 1999). The SFWMM was used extensively in evaluating ways to restore the flow dynamics of the pre-development Everglades. The area of the HSE model domain that overlaps with the SFWMM model domain consists of a regularly ordered triangular mesh – the remainder of the model domain consists of an irregular, triangular mesh. The use of a regular mesh in the overlapping areas allows the easy transfer of data between the two models (HSE and SFWMM) as well as an easy comparison of model results. In total, the HSE model domain consists of 1,271 triangular elements and covers an area of 5,770 km^2.

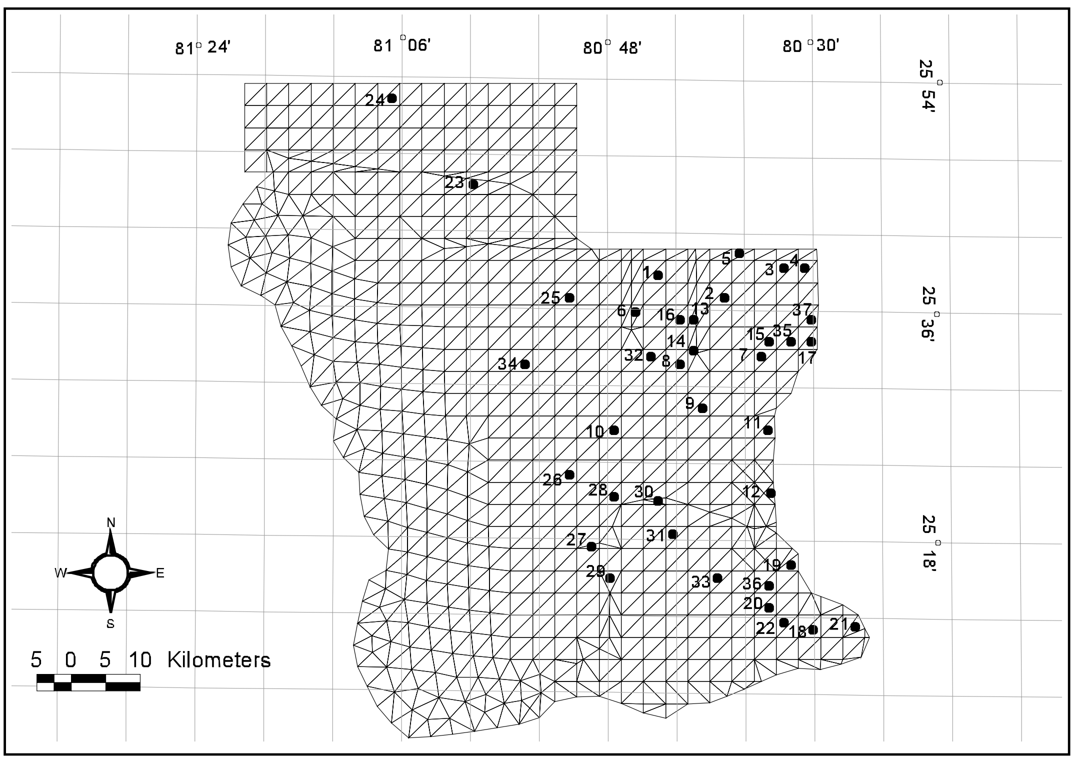

Figure 2 HSE Model Grid for Southern Everglades Showing Stage-Calibration Stations

The grid is illustrated in Figure 2. The HSE model domain extends farther to the southwest to include the mangrove and additional open-water areas (Figure 3). Land surface elevation and starting head values are prescribed at each element. The modeling domain constitutes a single canal structure located near the eastern edge of the model domain and just west of station FROGP or ID = 11 (Figure 2). It is a significant source of water to the eastern Everglades. The time variant inflows of this canal are defined using historical data.

The dynamic, constant-head boundary conditions provided by the SFWMM are used in the northern and eastern boundaries of the model. The western and the southern boundaries of the model, which coincide with the coastline, are fixed at zero NGVD. A daily time step is used in all model simulations. The model also requires input data for land surface elevation and several land-use and soil-texture based model parameters such as saturated hydraulic conductivity, surface roughness, aquifer thickness and specific yield, and evapotranspiration. Input data from the SFWMM were used as input to the HSE model in areas they have in common. Land-use classification, soil and elevation data used in the remainder of the HSE model domain were derived by using some of the data sets prepared by Lal et al. (1998). Based on satellite images, open-water and mangrove land-use classifications are assigned to the remainder of the HSE domain where they fall outside the SFWMM model domain.

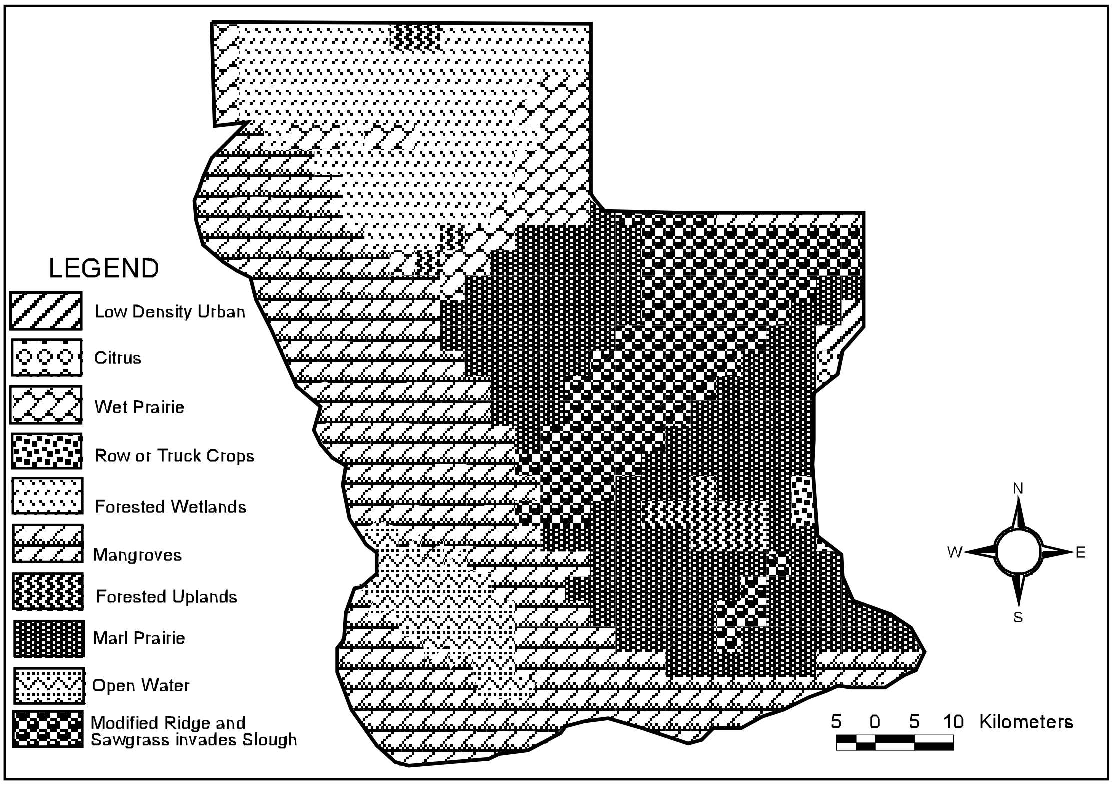

Figure 3 Land-use Classifications Used in the HSE Application in the Southern Everglades

There are ten distinct land-use types in the model domain (Figure 3). These are listed in Table 1 together with their respective surface areas and number of model elements with similar land-use. As given in this table, forest and wetland type land-uses cover approximately 95% of the watershed. In contrast, the areas with anthropogenic influence (urban and agriculture) cover only approximately one percent of the area of the watershed. The remainder of the watershed is covered by an open water area representing Whitewater Bay. The initial estimates of these model parameters are obtained by using published data, surrogate measurement statistics and best engineering estimates. Constant values are used to define the specific yield and bottom elevation of the aquifer. The remaining values are assumed to be correlated to land-use, and therefore, are varied spatially.

Model Calibration

All HSE model calibrations runs were conducted in an automated mode by using the Shuffled Complex Evolution (SCE) procedure developed by Duan et al. (1992). The SCE method "combines the strengths of the simplex procedure of Nelder and Mead (1965) with the concepts of controlled random search (Price, 1987), competitive evolution (Holland, 1975) and the newly developed concept of complex shuffling" (Duan et al., 1992). More details about the method are given in Duan et al. (1992).

Model calibrations were conducted by matching simulated water levels to observed water levels. Three most sensitive parameters, namely Manning roughness, evapotranspiration coefficients and saturated hydraulic conductivity were adjusted during the calibration process.

Table 1 Spatial Coverage of the Different Land-use Classes Used in the Model

Land-use Classification (Type)	Number of Elements	Area Occupied (km^2)	Percent Area
Low density (urban)	5	23.61	0.41
Citrus (agriculture)	3	11.05	0.19
Wet prairie (wetlands)	84	352.38	6.11
Row or truck crops (agriculture)	9	22.13	0.38
Forested wetlands (forest)	184	828.80	14.36
Mangroves (forest)	407	1,912.07	33.14
Forested uplands (forest)	30	134.65	2.33
Marl prairie (wetlands)	316	1,442.28	25.00
Water	51	246.47	4.27
Modified ridge and slough (wetlands)	182	796.16	13.80

Initially, stage measurements from 42 stage-measuring (gauging) stations were complied. All available weekly data from January 1988 to December 1995 were later identified. Due to lack of sufficient historical data, three gauging stations (RUTZKE, MONRD and BCNPA4) were discarded during the calibration process. Also, it was observed that a few gauging stations were in close proximity to one another such that assigning individual model cells to each of these stations did not warrant the effort. Observed water levels in selected groups of stations were averaged to represent observed water levels in certain cells in the model. The averaged water levels were used at three locations in the vicinities of BR105 and TAMI40; L67EXW and L67EXE; and NP_PH, EPGW and EPSW. The resulting "station names" are labeled as COMBO2 (ID = 23), COMBO3 (ID = 13), and COMBO4 (ID = 18), respectively. Therefore, during calibration, simulated stages at only 35 model cells or elements were compared with observed or historical measurements. Table 2 shows the final set of stations used. (Note that ID = 11 and 24 were discarded.) As shown in Figure 2, most of the stage-measuring stations are located near the eastern boundary of the model domain. Open water and mangrove occupy relatively large areas compared to the other land use types within the model domain. However, no gauging stations exist in these areas.

Discussion of Results

A summary of calibration results (both HSE and SFWMM) are given in Table 2. In the HSE, post-calibration root mean square error (RMSE) values for all gages improved substantially over the pre-calibration RMSE. The most significant improvements (post-calibration vs. pre-calibration) are obtained at gages COMBO4, FROGP and G3353. The mean (over 37 calibration cells) post-calibration RMSE value is 0.18 m. Since land surface elevations are known to be accurate within 0.15 m (0.5 ft) in the model domain, the RMSE values given here are acceptable for a variety of flow conditions simulated within the 1988-1995 period of record. Therefore, in a statistical sense, HSE simulated water levels and observed water levels in the ENP are in agreement.

The HSE tends to calibrate better in natural areas where stage fluctuations are small, e.g. EP12R and COMBO4; and tend to calibrate less effectively in areas where higher water level fluctuations exist, e.g. NP206 and NP44. The SFWMM shows a similar tendency. The SFWMM also calibrated extremely well in the central Shark River Slough area (stations NP-33, NP-202 and NP-203). On the other hand, the HSE calibration showed a fairly uniform degree of calibration within the same slough area.

The majority of available observed water levels fall under the marl prairie (17) and the modified ridge and slough (13) land-use classifications. The best-performing as well as the worst-performing stations in the HSE calibration seem to be clustered together and fall under the marl prairie land-use classification with an average RMSE of 0.17 m. The topographic ridge line (Figure 1) in the NE-SW direction that goes through the forested uplands define the demarcation between these two sets of stations. The average RMSE for stations with modified ridge and slough land-use is slightly worse at 0.19 m. Calibration grid cells with modified ridge and slough land-use classification are geographically concentrated within the Shark River Slough, the central flowway within the ENP. The SFWMM calibration does not show the same spatial pattern. On average, SFWMM calibration shows that stations with modified ridge and slough land-use (average RMSE = 0.14 m) tend to calibrate better than stations with marl prairies land-use (average RMSE = 0.16 m). The subtle difference as to which land-use classification was calibrated better (or worse) can be explained by the fact that the HSE calibration was done in a fully automated mode, whereas the SFWMM calibration was done manually.

Table 2 Comparison of Calibration (Historical Stage-Matching) Results for the Two Regional Hydrologic Simulation Models: HSE and SFWMM

ID	Station Name	Land Elevation, m	Land-Use Classification	RMSE for HSE	RMSE for SFWMM
1	NP201	2.26	MRS2	0.21	0.14
2	NESRS1	2.34	MRS2	0.18	0.15
3	NESRS2	1.74	MRS2	0.20	0.17
4	NESRS3	0.12	MRS2	0.21	0.18
5	G618	0.09	WP	0.19	0.17
6	G620	0.12	MRS2	0.19	0.16
7	G1502	0.58	MP	0.22	0.21
8	NP33	1.48	MRS2	0.17	0.10
9	NP206	0.64	MP	0.24	0.23
10	NP36	2.13	MRS2	0.16	0.13
12	FROGP	1.98	RC	0.13	0.10
13	COMBO3	1.98	MRS2	0.19	0.13
14	L67ES	0.49	MRS2	0.20	0.16
15	G3273	2.19	MP	0.22	0.21
16	NP202	1.83	MRS2	0.19	0.11
17	ANGEL	1.83	MP	0.24	0.21
18	COMBO4	1.71	MP	0.10	0.08
19	EVER4	1.83	MP	0.11	0.10
20	G3353	1.80	MP	0.11	0.11
21	EP12R	1.83	MP	0.07	0.08
22	EP9R	2.13	MP	0.11	0.14
23	COMBO2	1.74	FW	0.21	0.16
25	NP205	1.43	MP	0.22	0.19
26	NP35	1.92	MRS2	0.22	0.20
27	NP38	1.89	MP	0.13	0.13
28	NP62	1.54	MP	0.22	0.16
29	NP46	0.64	MP	0.11	0.16
30	NP44	0.34	MP	0.24	0.21
31	NP72	0.98	FU	0.22	0.23
32	NP203	0.30	MRS2	0.18	0.08
33	NP67	1.37	MRS2	0.13	0.13
34	NP34	0.34	MP	0.22	0.18
35	G596	0.34	LDU	0.25	0.26
36	G1251	0.43	MP	0.12	0.12
37	G1487	1.40	MP	0.23	0.23

*note: WP = Wet Prairie; MP = Marl Prairie; MRS2 = Modified Ridge and Slough; LDU = Low Density Urban
FW = Forested Wetlands; RC = Row or Truck Crops

In terms of average RMSE, the SFWMM calibration performed much better (difference in RMSE of at least 0.05 m) in eight locations: NP201, NP202, NP203, NP33, NP34, NP62, COMBO2 and COMBO3. However, only the calibration at station NP46 is significantly better in the HSE compared to the SFWMM. In terms of average bias (simulated – observed), HSE tends to overestimate stages in 25 stations and underestimate stages in 10 stations out of the 35 calibration grid cells; while the SFWMM tends to overestimate 20 and underestimate 15 out of the same set of grid cells. Overall, both models tend to overestimate stages within the model domain. A slightly larger error [100*(simulated – observed)/observed] in the HSE calibration compared to the SFWMM calibration (5.0 % vs. 2.9%).

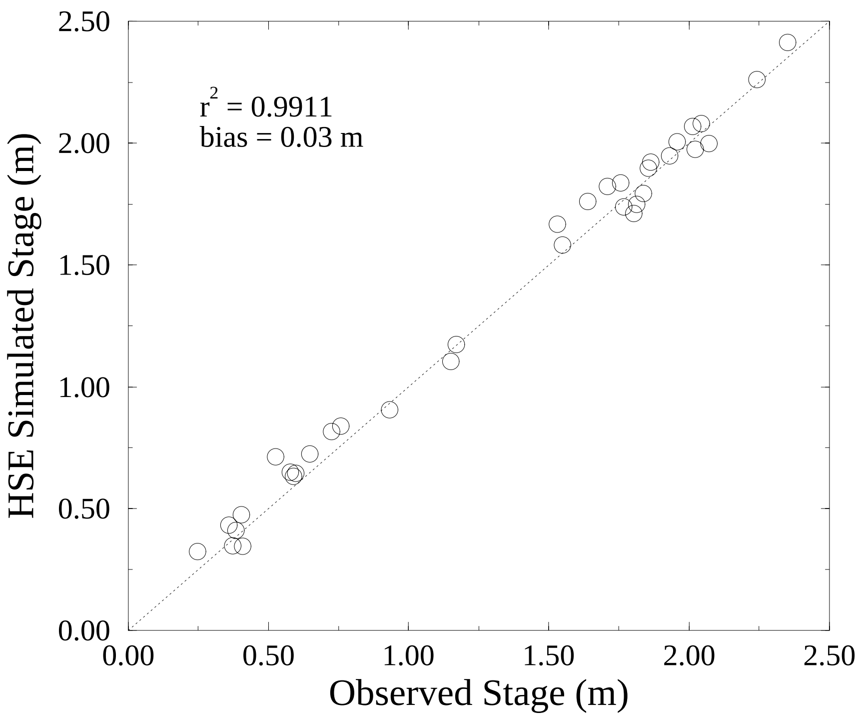

Figure 5 X-Y Plot of Average HSE-Simulated Stages Versus Historical Stages at Thirty-Five Calibration Stations in Southern Everglades Area

Figures 5 and 6 show simulated versus historical values on the y- and x- axes for the HSE and SFWMM calibrations, respectively. Although the average (over the 35 calibration grid cells) RMSE for the SFWMM is better than that for HSE (0.16 m vs. 0.23 m), the individual simulations relative to the observed values produced an r^2 (square of Pearson product moment correlation coefficient) of 0.989 and 0.991, respectively. The average bias (simulated minus observed stages over the 35 calibration grid cells) for the HSE and SFWMM are 0.03 m and 0.02 m, respectively.

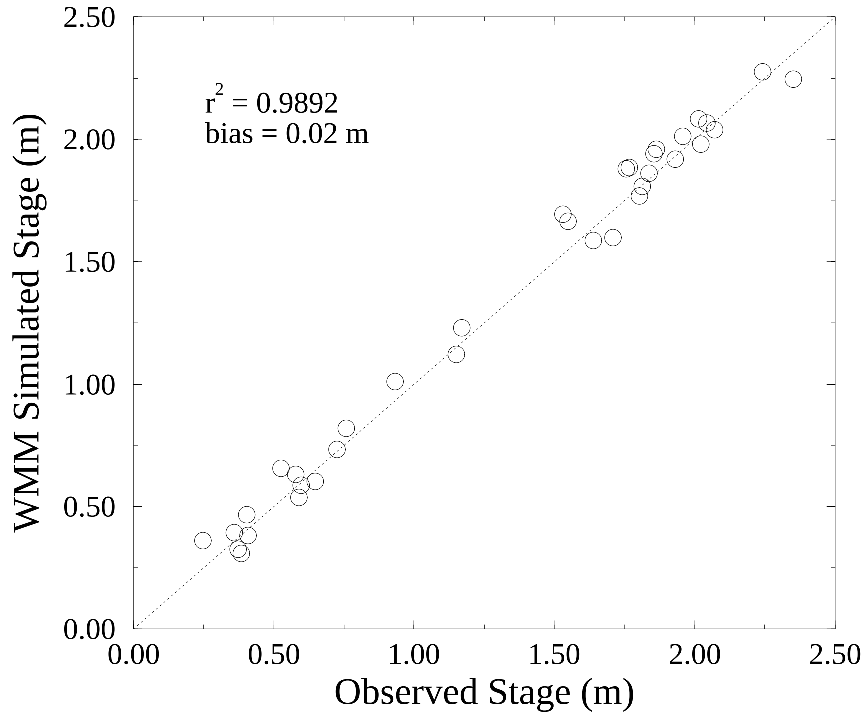

Figure 6 X-Y Plot of Average SFWMM-Simulated Stages Versus Historical Stages at Thirty-Five Calibration Stations in Southern Everglades Area

Summary

This paper represents an update of the current status of the next-generation regional simulation model for the Everglades. A preliminary comparison between the HSE and the more thoroughly-tested regional simulation model, the SFWMM, shows that calibration (history-matching of observed water levels) can be performed consistently between the two models. It should be noted that more types of calibration parameters were used in the SFWMM calibration compared to the current HSE calibration. Thus, the number of calibration "knobs" could play a role in establishing greater success in matching simulated stages with observed stages. The convenience of automatic calibration affords a similar degree of history-matching capability and should be exploited in future calibration efforts.

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